IOP | Institute of Physics
Nuclear Industry Group

NEWSLETTER
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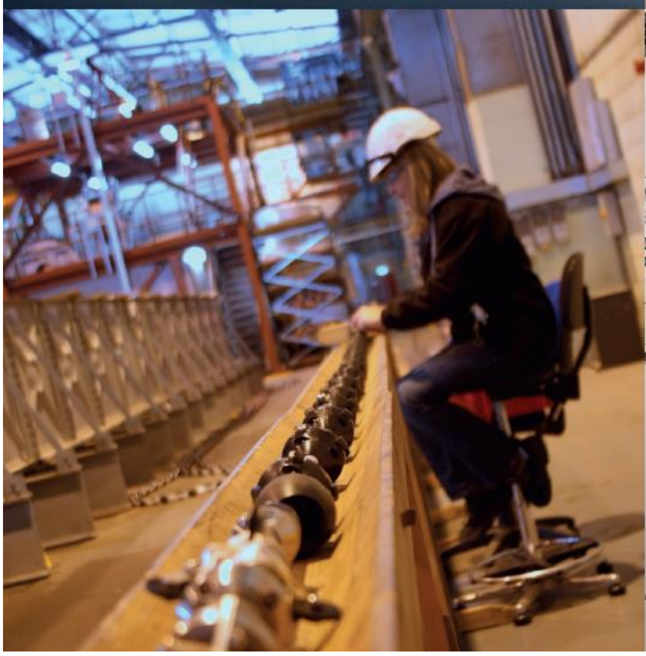


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Notes from the Chair

Welcome to all NIG members to this, my first “Notes from the Chair”. I was proud to be elected as the Chair of the Nuclear Industry Group last October, taking over from Geoff Vaughan as he stepped down as required by IOP rules following his four year term as Chairman. I was one of the founder members of the NIG and have been on the committee since the group was formed in 2010. I have been working in the Nuclear Industry for over 26 years in am currently the Head of Profession for Physics in Amec Foster Wheeler’s Clean Energy business. I have a wide ranging interest in many aspects of the nuclear industry and in encouraging the next generation of physicists into the industry.

My thanks, and those of the rest of the committee, go to Geoff for his hard work during his Chairmanship and in his continued support in helping me take over the role. My thanks also go to the other members of the committee for giving up their time to support committee activities and without whom the NIG would not be successful, and smooth running. This has also been the first year as Honorary Secretary for Zahid Riaz of ONR, thanks to Zahid for organising and hosting one of our evening events and contributing to other events. The thanks of the committee also go to our Honorary Treasurer Chris O’Leary who is stepping down having completed his term. This role is up for election and you should have seen the call for nominees that was recently published. There is more about this later in this newsletter. Just as important as the three Officers is the whole committee: some members have responsibility for certain roles: Newsletter editor (Alfie O’Neill has taken over my old role as Newsletter editor, and I’m sure you will agree has done a great job with this letter). Communications are handled by Claire Elliott (another essential part of the NIG); Social media (Dale McQueen is running the Facebook account and Chris O’Leary is monitoring LinkedIn.); other committee members, including David Weaver one of our newer committee members have also organised events and all have contributed in innumerable other ways.

Over the past year, we have run five successful events that you can read about later in this letter, with diverse topics covering many aspects of the industry. IOP produced a short video diary at our evening lecture by Sue Ion and you can view this on the IOP website via YouTube here: http://bit.ly/2wKrK1w. There has been a mixture of early-evening events timed to allow attendance after work and a half day event on nuclear fusion. Our events have had a geographical spread with venues at the Birchwood Centre near Warrington in the North West, Birmingham University, and Harwell near Oxford. We plan to continue covering a range of geographies with our forthcoming events for the remainder of 2017 and into 2018. This year we also co-sponsored a day meeting organised by the Materials and Characterisation Group on the Characterisation of Materials used in Nuclear Environments which was held in London and we attended the ENYGF (European Young Generation Forum) conference along with IOP to help promote physics and the IOP.

We have a couple of forth-coming events already scheduled for this year and into 2018, and will be organising more throughout the year. Notably we were pleased to win a grant from the IOP to hold a Topical Research Meeting titled ‘Physics.Innovation.Nuclear’. You can find out more about this and book attendance via this link: http://bit.ly/2xcv6xh. Thanks go to Dale McQueen and his team for all the effort that they have put into organising this event. For IOP members the cost of attending this event is capped at £75 which includes the conference dinner that will be held in MOSI (the Museum of Science and Industry), a fitting venue for a conference. I hope to see a good attendance at this event as we will have some interesting and high profile speakers on a range of topics. In March 2018 we will be holding an evening lecture in conjunction with awarding the group prizes for 2018. We will be pleased to welcome Jim Gulliford from NEA who I am sure will have an interesting talk for us. More details will be released nearer the time.

I attended an IOP Groups Business Planning event earlier this year at IOP HQ in London with the aim of networking with other groups. IOP produced some statistics showing the spread of different group memberships. This is no surprise that nearly half of our group membership are also in the Nuclear Physics Group and 35% are also in the Energy Group. What I found interesting was the diversity of other groups our membership also belong to, across the 48 active IOP groups, members of our group are also in every other group. It was also noteworthy how diverse the other groups in IOP are and where synergies lie between groups. This led to some interesting conversations around potential joint events. We are already in the planning phase for a joint event with the Women in Physics Group for early next year and will be running other events as well, some of which are discussed at the end of this newsletter. We have others in the pipeline so keep an eye on your emails for new events.

This has been an interesting and varied year for the industry, with one of the key topics with the potential to impact across all sectors of the industry was the government's announcement that the UK would withdraw from the Euratom Treaty as part of Brexit. As chair of the NIG I was invited, along with others from our committee to be part of a policy group on the implications of leaving Euratom on the industry and helped to produce the IOP policy statement on this. You can read more about this later in the newsletter.

I hope that you find this newsletter interesting, as always we value the comments and suggestions of you, our members, and any suggestions of event topics that you would find interesting or would like to participate or see us explore further would be welcomed so do please get in touch. On that note wishing you all a successful year.

Heather Beaumont
Chair - IOP Nuclear Industry Group

IOP Group Officers Forum

Article by: Zahid Riaz

In my capacity as secretary of the NIG I attended an IOP Group Officers Forum last November. The forum provides an opportunity for group officers to discuss the work of IOP groups and network with other IOP Groups with which they might hold a joint event.
Some of the items discussed which are still relevant or of interest to NIG members are listed below:

- The new IOP building will be occupied from spring 2018, with the formal opening happening in July 2018.
- Changes to the IOP membership structure were discussed. The summary below lists the main changes that have been developed since the discussion and which will be implemented:
    1. Simplifying our membership structure from seven to four categories, making it much easier to join and progress through the different levels of membership. The new levels will be Associate Member, Member, Fellow and Honorary Fellow.
    2. Creating a fairer fee model that benchmarks favourably with other societies and aligns well with the new structure.
    3. Introducing a fee of £15 for undergraduates and trainees to allow us to offer a wider range of benefits and more proactively support these members.
    4. There will be a standard concession rate (applicable to part-time, retired, low-income, career-break and students) set at 30% of the full fee for each level of membership i.e. Associate Member, Member or Fellow.

    IOP intends that all members will have been transferred into the new membership structure and fee model by November 2018..
- Group annual newsletters will only be printed in black and white. IOP has urged all groups to send newsletters to their members via e-mail. Just to remind you this is the last year that the NIG will be posting out newsletters to all members, unless they specifically request a

paper copy! So please let Alfie O'Neil, the newsletter editor, know if you wish to continue to receive a paper copy of the newsletter.

- The IOP has available a significant 'Benevolent Fund'. The following text was taken from the IOP website and provides more details:

  "This was established in 1924 by the first honorary treasurer, Major CES Philips. Over the years the fund has grown through the generosity of members of the Institute and members are still encouraged to support the fund by donations and bequests. The 'Benevolent Fund' provides financial help to physicists, or their dependents, facing a critical need that cannot otherwise be met. Typically, it provides essential help to ease the burden of unemployment, sickness, financial hardship in old age, or it can help whilst on a career break. All enquiries and requests are dealt with in the strictest of confidence. Letters marked Private and Confidential should be addressed to The Secretary of the 'Benevolent Fund', 76 Portland Place, London WIB 1NT or email benfund@iop.org."

  The 'Benevolent Fund' committee meets periodically during the year to consider applications for support but procedures exist to deal quickly with urgent cases.

  Members considering a bequest to the 'Benevolent Fund' should contact its secretary for further information.

- A talk was given by a member of the IUPAP (International Union of Pure and Applied Physics) on its purpose and work. The following information was taken from its website at http://iupap.org/ where more information about it can be found.

  "The union was established in 1922 in Brussels, and currently represents 60 countries. The UK representatives are Professor Paul Hardaker and Tajinder Panesor both from the IOP.

  The mission of the union is: *"**To assist in the worldwide development of physics, to foster international cooperation in physics, and to help in the application of physics toward solving problems of concern to humanity**".*

  The aims of the union are:
  - To stimulate and promote international cooperation in physics.
  - To sponsor suitable international meetings and to assist organizing committees.
  - To foster the preparation and the publication of abstracts of papers and tables of physical constants.
  - To promote international agreements on other use of symbols, units, nomenclature and standards.
  - To foster free circulation of scientists; to encourage research and education.

  The union supports and endorses conferences and has fifteen current working groups which are an international and interdisciplinary collaboration of researchers aiming to focus and develop new research fields and activities that would be difficult to resource through traditional funding programmes."

NIG Committee Elections

The NIG is now seeking four committee members and would like to invite nominations for the post of Honorary Treasurer and three posts of Ordinary Member.

To be eligible for nomination you must be a member of the IOP and a member of the NIG. All grades of membership are eligible for Ordinary Member posts.

An Ordinary Member may take on a variety of roles, such as, for example, being members of the prize committee, being the annual newsletter editor, being responsible for the website and social media for the group. Others may do one-off tasks such as organising an event or lecture. There is also the opportunity to comment on IOP policy documents and responding to requests for views on government consultation documents to inform the IOP response within the group's scope.

To be eligible for nomination as Honorary Treasurer a person must be a corporate member of the Institute (MInstP, FInstP or HonFInstP) and a member of the group. They should also be proposed and seconded by group members (committee members may act as proposers / seconders).

The Honorary Treasurer is responsible for managing and monitoring the group's spending, ensuring it complies with IOP regulations. They should use the allocated funds effectively and in a manner consistent with the group's aims; other members of the group will seek guidance from them on requests for funding of talks, seminars, conferences and other activities. They authorise expenditure (invoices, expenses), request payments (e.g. BACs payments to prize winners), and complete the funding request form (by early September the preceding year) in consultation with the committee. They may also give a brief financial report at the group AGM.

The call for NIG committee members will be sent out via email to all NIG members in September by IOP. It is also noted that it would be great if someone from the fusion community could volunteer to serve on the NIG committee from 2017 to 2021.

If you would like to informally discuss the roles, please contact any of the following:

Ms Heather Beaumont, Honorary Chair, Heather.Beaumont@amecfw.com
Dr Chris O'Leary, Honorary Treasurer, Chris.OLeary@Rolls-Royce.com
Mr Zahid Riaz, Honorary Secretary, zahid.riaz@onr.gov.uk

Nuclear Industry Group Career Contribution Prize 2017

Article by: Alfie O'Neill

This year the Nuclear Industry Group awarded a Career Contribution Prize at the AGM held in February 2017.

The Career Contribution Prize is for a physicist who has spent a substantial portion of their career in the nuclear industry. It is to be awarded to the nominee who the judging panel feel has most fully displayed outstanding levels of innovation and contributed to the progress of the industry over a sustained period. The nominee must have displayed outstanding commitment to the promotion of the nuclear industry throughout their career.

Once again the calibre of entrants was high and selecting a worthy winner was a difficult process, but we are pleased to announce that this year's Career Contribution Prize was awarded to Steve Curr of Rolls-Royce.

Steve's extensive and varied career in the nuclear industry has spanned just over 40 years, starting as an apprentice at 'Rolls-Royce and Associates' in the mid-1970s and rising to the position of 'Rolls-Royce Engineering Fellow for Reactor Core Design' and 'Chief Technologist for Reactor Core Design and Manufacture'. Steve has driven his career through numerous leadership roles at Rolls-Royce in spheres of technical, people and project management in support of the UK Naval Nuclear Propulsion Programme (NNPP). Steve played a key role in the core design for the Dreadnought Class boats and is currently leading on the reactor physics aspects of a new concept Small Modular Reactor (SMR) for consideration by the UK government.

Steve has served on important national working group committees throughout his career, including as the Chair. He has delivered substantial training to engineers working in the nuclear industry and has won national awards for such. He has further leant support to the MSc Physics and Technology of Nuclear Reactors course at the University of Birmingham through both lecturing and provision of funding over a sustained period. Steve has also served on the editorial board of the Nuclear Engineer journal.

Steve is a Chartered Physicist (CPhys) and a Fellow of the Institute of Physics (FInstP); in addition to holding Chartered Engineer (CEng) and Chartered Scientist (CSci) status. He has supported the IOP, not least in being an assessor for Fellowship candidates and I'm sure you'll agree is a worthy recipient of this award.

The calling notice for the 2018 Nuclear Industry Group prizes will be released later this year where we will be looking for nominations for both an Early Career prize and a Career Contribution prize. So please get your thinking caps on now and seek out those collleages and friends worthy of recognition!

Speaker Dame Sue Ion presenting Steve Curr with his Career Contribution Prize on behalf of the Nuclear Industry Group prize committee.

Event – Gen IV Reactors by Richard Stainsby (NNL)

Article by: David Weaver.

This event[1] was held in collaboration with the University of Birmingham[2], November 2016.

Generation IV reactors are future designs beyond the current Generation III/III+ forms currently in operation or being considered. Gen IV Reactors are designed to be: (i) Sustainable (better use of natural uranium, avoidance of greenhouse gas emissions, displacement of fossil fuels from process heat markets and minimisation of spent fuel wastes); (ii) Economical; (iii) Safe –as safe as, or safer than current Gen III+ reactors; (iv) Proliferation Resistant.

Concerning Sustainability, nuclear power with today's Gen II & III/III+ reactor technologies already avoids significant greenhouse gas emissions; however, barring some applications to seawater desalination and district heating, little use has been made of nuclear-generated process heat. But uranium is a finite resource (~100 years "conventional" U remaining) which fuels current Gen II/III reactors. Admittedly, plutonium extracted from spent fuel can be used as a fuel, but Gen II/III reactors make inefficient use of it. Globally, natural uranium has 7×10^6 tonnes of known reserves, with 10.4×10^6 tonnes of speculative reserves[3].

The 500 kg of uranium in a fresh fuel element, enriched to 4% ^{235}U, implies there are 20 kg of fissile ^{235}U. After use, the spent fuel is 475 kg of U, but with only 0.9% ^{235}U. There are also 20 kg of fission products (FP) and 5 kg of plutonium making a total of about 9.3 kg of fissile material, so spent fuel is not so spent!

Minor Actinides (MA) (i.e. Transuranic elements) make up a small fraction of heavy elements produced in the reactor through neutron captures in plutonium to form, principally, Am, Cm and Np. Whilst a small fraction of waste, these are very radiotoxic and have long half-lives. At present MA go to disposal along with spent fuel (where there is no reprocessing) or with the FP (if reprocessed). If spent fuel is sent straight to disposal the relative radiotoxicity of the combination of FP, MA and Pu, while starting at about 1000 times that of mined uranium ore, will only reach the same relative radiotoxicity as the ore after 250,000 years. With reprocessing and Pu recycled, the FP and MA go to disposal and reach the same relative radiotoxicity as fresh mined ore after 10,000 years. Finally if "Partitioning and Transmutation" (P&T) of minor actinides can be employed, only the FP go for disposal and the relative radiotoxicity reaches that of fresh mined ore after ~300 years, demonstrating the benefit of removing Pu and MA from HLW. Hence a desire to form closed loop fuel cycles where actinide recycling is employed. Gen IV designs focus on closed loop systems.

Regarding nuclear process heat, lower temperature applications (e.g. desalination, and district heating) use waste heat so can be served by all reactors types. Higher temperature applications (e.g. chemicals production, oil refining, hydrogen production or advanced steelmaking) can only be served by the High Temperature Gas-cooled Reactor, or HTR (HTGR).

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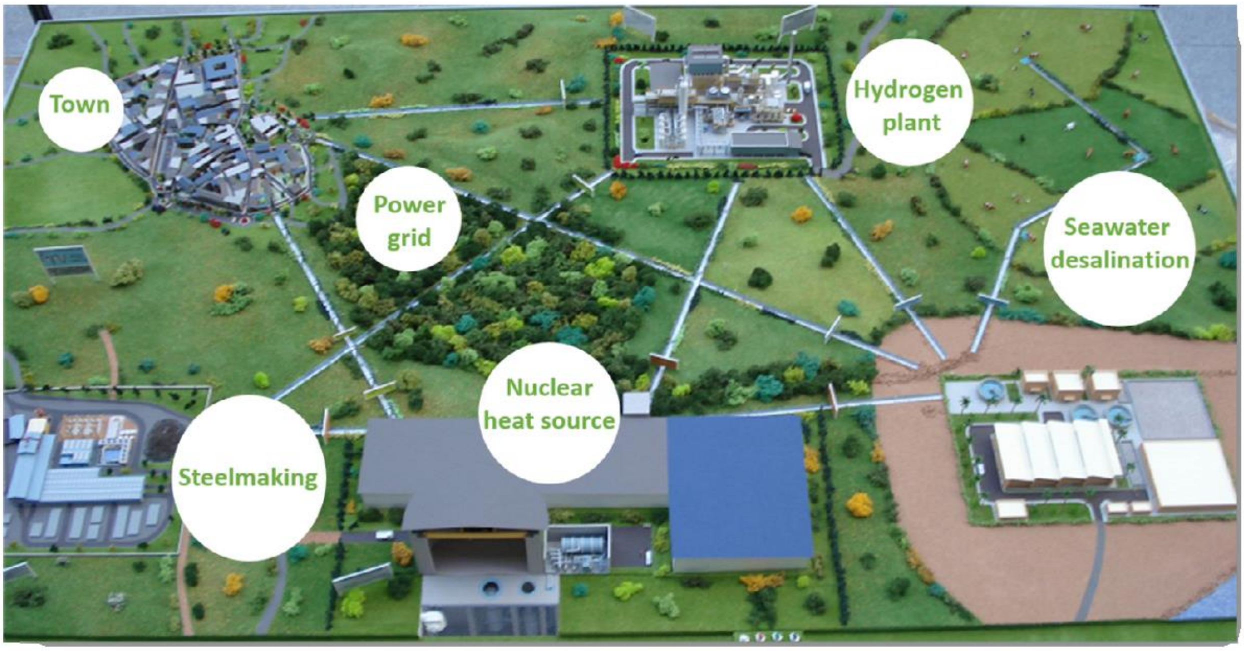
[1] Richard Stainsby is a recent Ex-Chair of the GFR System Steering Committee and Euratom member of the SFR System Steering Committee.
[2] As this talk was collaboration between IOP NIG and the University of Birmingham, the audience was composed of a broad spectrum of physicists and engineers. The speaker tailored his content to account for this; however, this summary has omitted simple background fission power information.
[3] 2011 OECD/NEA-IAEA "Red Book".



Example power grid for a nuclear process heat system, taken from Richard's slides.

Thus "New" technology is needed to make better use of natural uranium – better by two orders of magnitude - while reactor operating temperatures need to be increased dramatically compared with Gen II/III/III+ to become a versatile source of process heat. However, there is a "zoo" of options: fuel nuclides and chemical form, clad types, moderator types (including none) and coolants. Following a review of basic fission physics, the talk focussed on the ingredients of a self-sustaining closed fuel cycle. There are three important commodities: a stock of fissile material; a stock of fertile material and excess neutrons. The first dictates the size of the reactor fleet, while the second dictates how long the fleet can operate. Finally, some of the excess neutrons beyond those needed to sustain the nuclear reaction must be absorbed by ^{238}U to transmute it to Pu. The more neutrons that do this the higher the breeding ratio.", i.e. avoiding leakage and absorption in everything other than ^{238}U.

Considering breeding in an LWR fleet: all reactors that contain ^{238}U will breed Pu. The measure of how good a reactor is at breeding is the "conversion ratio" (= the breeding ratio),

C = number of fissile items created / number of fissile atoms consumed

For thermal reactors C < 1. For fast reactors C ≥ 1 (but can be < 1 by design). Starting with N fissile atoms, after one irradiation we get C×N fissile atoms. Thus after many cycles the total number of fissile atoms is

$$N_T = N + CN + C^2N + C^3N + C^4N + \dots$$

For C < 1, $N_T \rightarrow N / (1 - C)$, so for a LWR where C ~ 0.5, $N_T \rightarrow 2$ N. Conclusion: large-scale MOX recycle in LWRs results in very limited conservation of uranium.

In contrast, using fast reactors we can increase the amount of fissile material available by a factor of up to 100 because:

$$N_T = N + CN + C^2N + C^3N + C^4N + \dots \rightarrow \infty \text{ for } C \geq 1$$

In reality we are limited by the amount of ^{238}U that we have, but we still have enough fuel to last for about 4,000 years! And as much again, or more, using thorium reserves.

Taking figures from Boullis (CEA, November 2011) potential world energy reserves without fast reactors amount to: Coal: 400 Gtoe (Gigaton of oil equivalent); Oil: 165 Gtoe; Gas: 150 Gtoe and U: 40 Gtoe. With fast reactors the U component rises to 4,000 Gtoe.

The talk then reviewed the designs being considered in the Gen IV project.

Gen IV Thermal Reactors

	Very High Temperature Reactor (VHTR)	Super-Critical Water Reactor (SCWR)	Molten Salt Reactor (MSR)
Fuel	U	U	Pu/U, Pu/Th or U/Th
Fuel form / clad	Oxide / coated-particle	Oxide / metal	Molten salt
Moderator	Graphite	Light or heavy water	Graphite
Coolant	Gas	Light water	Molten salt

Gen IV Fast Reactors

	Sodium-Cooled Fast Reactor (SFR)	Gas-Cooled Fast Reactor (GFR)	Lead-Cooled Fast Reactor (LFR)	Molten Salt Fast Reactor (MSFR)
Fuel	Pu/U	Pu/U	Pu/U	Pu/Th or U/Th
Fuel form / clad	Metal, oxide or nitride / metal	Carbide / ceramic	Oxide / metal	Oxide or nitride / metal
Coolant	Alkali liquid metal	Gas	Heavy liquid metal	Molten salt

For more details, including the Technology Roadmap for Generation IV Nuclear Energy Systems (2002) see the Generation IV International Forum (GIF) website: https://www.gen-4.org

SFR

With an outlet temperature of 530-550ºC and a pressure of ~1 bar in the primary pressure vessel, the design has a rating of 1,000-5,000 MW(th) [average power density 350 MW(th)/m^3] from a metal or oxide fuel in ferritic or ODS[4] ferritic clad. An average burn-up of ~150-200 GWd/MTHM[5] is predicted. The design uses an intermediate heat exchanger between the primary vessel and the steam generation loop and produces a Conversion Ratio (C) of 0.5-1.3. Superphenix at Creys-Malville in France was shown as an example of a demonstration plant. Mention was made of DFR and PFR at Dounreay; the research and design work demonstrated led to the UK Government supporting membership of the European Fast Reactor project (with France,Germany and Italy). Current SFR concepts include the “Pool type” ASTRID in France and the “Loop type” JSFR in Japan and the BN800 reactor in Russia.

GFR

With coolant inlet/outlet temperatures of 490/850ºC and a pressure of 90 bar, the design has a rating of 600 MW(th) [average power density 100 MW(th)/m^3] from a UPuC/SiC (70/30% & ~20% Pu content) fuel. The design predicts a burn-up of 5% FIMA[6] and a damage rating of 60 dpa. The Conversion Ratio (C) said to be “self-sufficient”. A number of parameters were emphasised: helium coolant (which is (i) transparent, unlike Na in the SFR, (ii) chemically and neutronically inert but (iii) requires high coolant pumping power); a fast neutron spectrum; a high outlet temperature thus high efficiency; a strong Doppler effect and a weak void effect. Decay heat removal (as a result of a LOCA) is affected by its high power density and low thermal inertia.

A reference GFR core has been considered by CEA. It is a cylindrical core filled with hexagonal subassemblies, containing a triangular pitch rod array. The fuel is (U,Pu)C with a cladding of SiC/SiC CFCMCs[7] with an internal metallic liner for leak tightness to prevent fission gas release to the coolant. Although the plate type concept is attractive, fabrication difficulties emerged that led to focus on a classic pin concept.

[4] ODS = Oxide Dispersion Strengthened.
[5] MTGM = Metric Tonnes of Heavy Metal.
[6] FIMA = Fissions per Initial Metal Atom.
[7] CFCMC = Continuous Fiber Ceramic Matrix Composite.

LFR

[Unlike the SFR and GFR, the diagram in the talk did not contain as much detail. For more information see the GIF website.]. However, the talk did provide some information on the 10-100 MWe Small transportable system (SSTAR) for which evolutionary changes may include: Forced cooling; Oxide fuel and a Steam Cycle. Also mentioned were the 600 MWe ELSY and its evolution into the design for the European Lead Fast Reactor (ELFR).

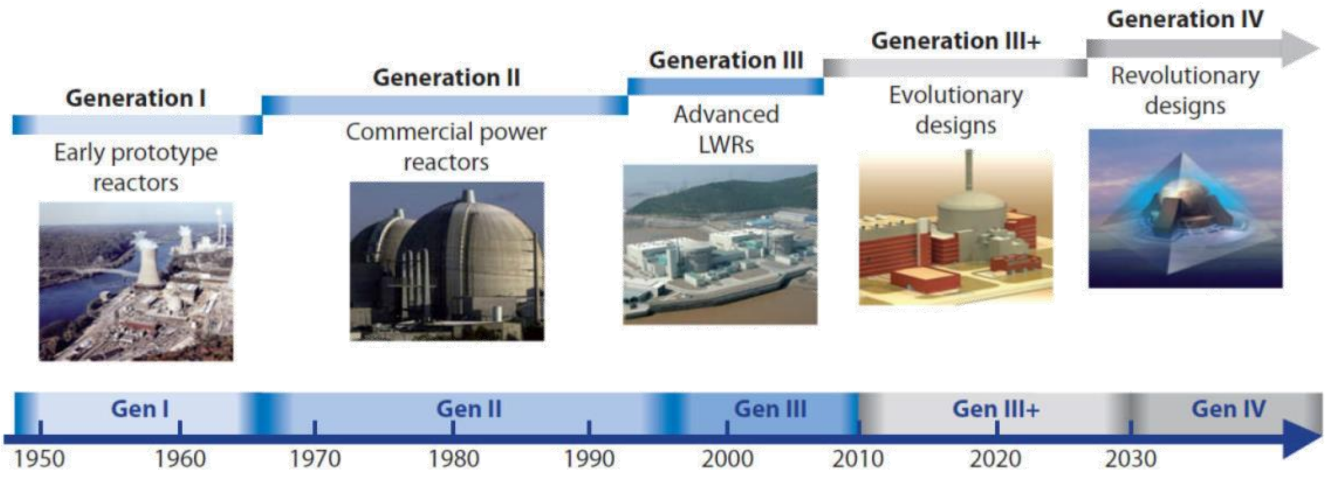
MSR

The original Gen IV concept uses an epithermal neutron spectrum a liquid fuel which is also the primary coolant. With a net power of 1,000 MW(e) [power density 22 MW(th)/m^3] it achieves a net thermal efficiency of 44-50%. The moderator is graphite. The fuel salt has an inlet temperature of 565ºC and outlet at 700ºC (850ºC for hydrogen production). A multi-reheat recuperative helium Brayton cycle forms the power cycle.

MSFR

The MSFR "Closed On-Site Fuel Cycle" (in Equilibrium Conditions) has a feed of ^{238}U or ^{232}Th. FP+U+Pu+MA (Am, Np, Cm) are extracted and sent to an on-site reprocessing plant where FP are removed. The U+Pu+MA are then fed back to the reactor. The MSFR concept can maintain a sustainable breeding reaction with thorium.

In concluding it was noted that the case made for the development of Fast Breeder Reactors made in the 1940's through to the 1980's is still relevant today. There is a tendency to base decisions about the long term development of fast reactors and closed fuel cycles on the spot price of uranium and reprocessing costs at the time the decision is taken. However, spot prices of commodities just reflect demand at that time and do not necessarily reflect the scarcity of the resource. The majority of systems being considered in Generation IV are fast reactors (or have fast spectrum variants). Without fast reactors, nuclear fission will have a lifespan of only about 100-200 years. However, with fast breeder reactors we can generate thousands of years of electricity (and other energy forms) using a small refinement of 1970's technology. Even if the fuel supply arguments are discounted, fast reactors offer an effective means to manage the build-up of spent fuel from Gen II/III plants and to manage Pu stockpiles.



Evolution of reactor designs, taken from Richard's slides, available on the NIG website.

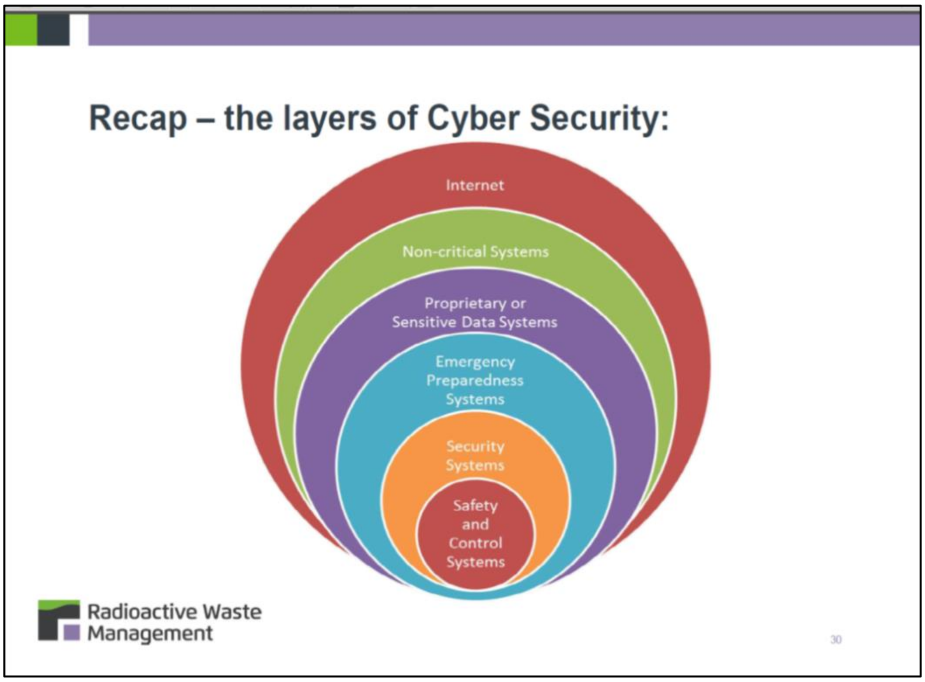
Event – Nuclear Security by Robert Rodger (NNL) and Graham Urwin (RWM)

Article by: Lucy Bailey.

On 15 November 2016, the IoP NIG hosted a double bill nuclear security event at Harwell.

Robert Rodger of the National Nuclear Laboratory opened the event with an informative overview of safety, safeguards and security. Robert described the sources of potential hazards that may pose challenges to nuclear security and the structure of the legislative framework based on binding international treaties such as the Convention on the Physical Protection of Nuclear Material, the International Convention for the Suppression of Acts of Nuclear Terrorism and United Nations Security Council resolutions. Vulnerability assessments were discussed with examples of preventative controls and preparedness controls providing defence in depth against threats. The process and considerations for preparing a nuclear site security plan were outlined, with emphasis on the importance of instigating a strong security culture.

Graham Urwin, Security Manager at Radioactive Waste Management Limited (RWM) then gave a lively presentation on cyber and information security. Graham explained how the UK is investing £1.9 billion in its 2016-2021 national cyber security strategy to defend the UK against evolving cyber threats, to deter aggression in cyberspace by making the UK a hard target and to develop an innovative cyber security industry. Current trends in UK cybersecurity were discussed, these include identity fraud and online extortion demands. It was noted that phishing emails are becoming more sophisticated, with fraudsters gaining personal information, addressing targets by name and posing as real companies with whom the target deals. Personal information is often gained in small steps by confidence tricks, so it is important that everyone is vigilant in not divulging any personal information to any unknown parties. Finally, Graham provided references to the various resources available to help combat cyber-crime.



The slides from both presentations are available on the IoP NIG website.

Event – The UK's Nuclear Future by Dame Sue Ion

Article by: Alfie O'Neill

This talk was held in Birchwood on the 28th February 2017, hosted by the IOP NIG.

A bright future

Dame Sue Ion opened her talk with a summary of progress made by the nuclear industry in 2016: two European Pressurised Reactors (EPR) at Hinkley Point C were given permission for construction to begin, the Department of Energy and Climate Change awarded a grant to build a materials testing laboratory at the High Temperature Facility in Warrington, the government launched a competition to choose an Small Modular Reactor (SMR) design for the UK to develop and with the end of Magnox reactor operations and the clean-up and decommissioning work ongoing at Sellafield Sue concluded that you couldn't be in the sector at a better time.

The role of NIRAB

Dame Sue Ion explained the role of NIRAB, the Nuclear Innovation Research and Advisory Board, which she chaired over its three year tenure. NIRAB was set up in 2011 after it was identified by government that the UK faces "crucial gaps in capabilities" in the nuclear sector. The role of NIRAB was to advise government on priorities for UK nuclear R&D, promote innovation and foster cooperation across academia and industry. NIRAB aimed to ensure the UK is a key partner in commercialisation of Generation III+, IV and SMR reactor technologies, and that the UK remains a 'top table' nuclear nation. NIRAB focussed on areas where government funding is needed, since industry cannot or will not invest in research projects with significant lead times and uncertainty or high development costs. Once commercialisation of the research is identified it is expected that industry will take over.

In February 2017 NIRAB issued its final report which made recommendations to the Department for Business, Energy and Industrial Strategy (BEIS) for research in five key areas:

- Future fuels – making more efficient safer reactor fuels.
- 21st century nuclear manufacture – using advanced materials and manufacturing techniques.
- Reactor design – delivering people, processes and tools to make the UK a partner of choice for SMR and Gen IV designs.
- Recycling fuel – developing cost effective technologies for a sustainable low carbon supply chain.
- The UK's strategic toolkit – informing decisions on emerging nuclear technologies which could be brought to the UK market.

Earlier this year BEIS launched a £20 million funding programme for the initial phase of these recommendations, NIRAB expect the total cost of delivery to be around £250 million.

UK Strengths

The UK has a strong and varied nuclear industry, Sue Ion highlighted some of the areas where we are world leading. We have an involvement with a large range of reactor designs, and although we've not kept up with Gen IV developments internationally this is an area government agree we should invest in. The UK has expertise and experience across the fuel cycle, and in waste management and decommissioning. Industry also benefits from government support and word leading R&D facilitates, including Europe's largest cave-line. However, Sue did highlight that although the UK does lots of work with basic science in universities and academia and in technology development in industry we are weaker and underfunded in the area between these.

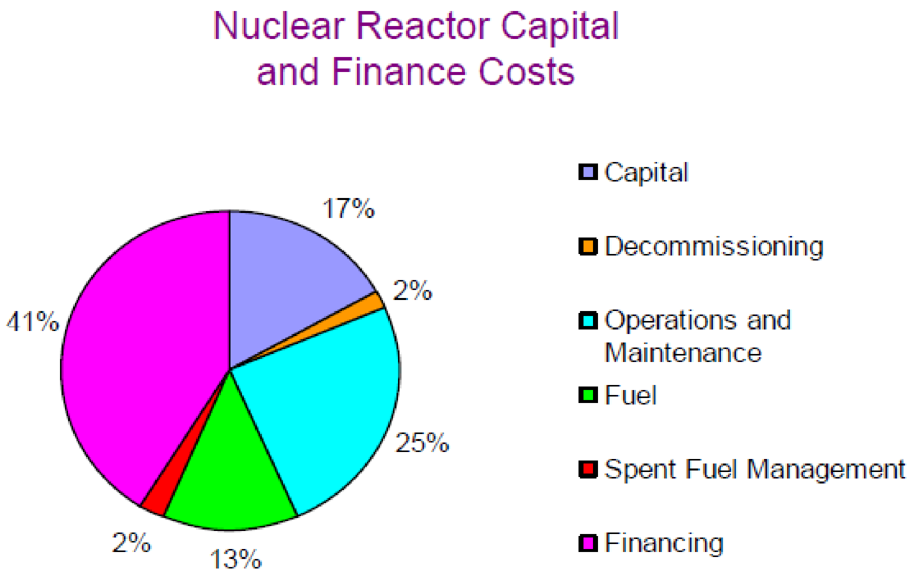
The Grand Challenges

The most significant challenge now facing the UK nuclear industry is to translate these policies identified by NIRAB into practice. This will be underpinned by the successful delivery of the first wave of nuclear new build and by continued progress in the remediation of legacy issues at Sellafield.

Nuclear New Build

Dame Ion highlighted some the challenges and achievements in the UK's nuclear new build project. As can be seen in graph, the cost of building a typical LWR is dominated by capital to construct and finance before returns flow:

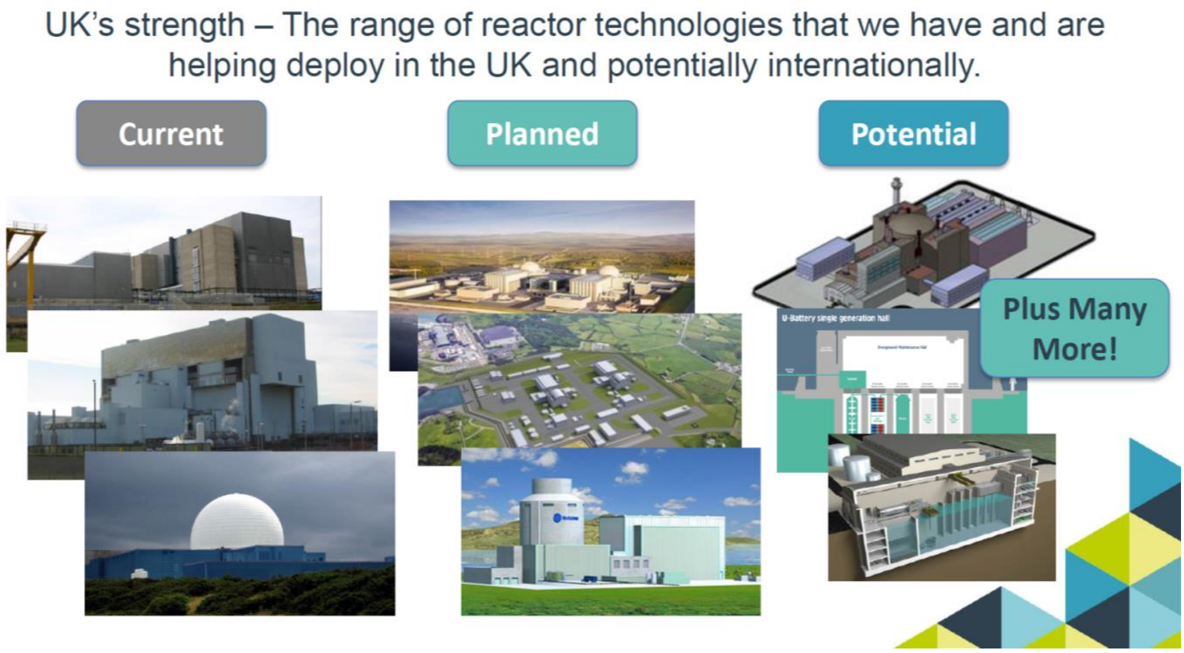
Sue discussed the advanced technologies flowing into the concrete used at Hinkley Point C, using digital modelling of rebar to minimise construction risk, and a new modular design and assembly process which significantly reduces the site labour required.



Breakdown of the typical costs for a nuclear new build project.

Looking further ahead Dame Sue discussed the UK's fast breeder reactor history at Dounreay and the benefits and challenges in perusing a fast breeder reactor programme. Another option being considered by government are Small Modular Reactors but with many designs being presented globally policymakers need to provide direction to industry. A further potential market is in thermal reactors, providing both heat and power to industry and consumers. In order to meet our future energy needs and fulfil any policy pursued the UK will require a strong and broad skills base. Dame Sue concluded her talk with some of the flagship UK facilitates and recent achievements.

The slides from Dame Sue Ion's talk are available on the IoP NIG website



Event – Regulatory Challenges for Nuclear New Build by Mike Finnerty.

Article by: Zahid Raiz

Mike Finnerty, Deputy Chief Inspector and divisional director of the 'New Reactors Division' at the Office for Nuclear Regulation (ONR) presented on the subject of 'Regulatory Challenges for Nuclear New Build' at 'The Centre' Birchwood on the evening of 17th of May. This article presents a summary of his presentation.

Mike started his presentation by introducing the ONR and its work.

'*The ONR's mission is to provide efficient and effective regulation of the nuclear industry, holding it to account on behalf of the public*.'

ONR independently regulates nuclear safety and security at 36 nuclear licensed sites in the UK. It also regulates transport and ensures that safeguards obligations for the UK are met. ONR's duty is to ensure that the nuclear industry controls its hazards effectively, has a culture of continuous improvement and maintains high standards.

ONR must do this with an 'Enabling Approach' following the 'UK Regulators' Code' i.e. in a manner which enables those it regulates to both comply and grow.

Mike's presentation described the three elements of ONR's regulation of nuclear new build:

- Generic Design Assessment (GDA)
- Licensing
- Construction

These are discussed in turn below.

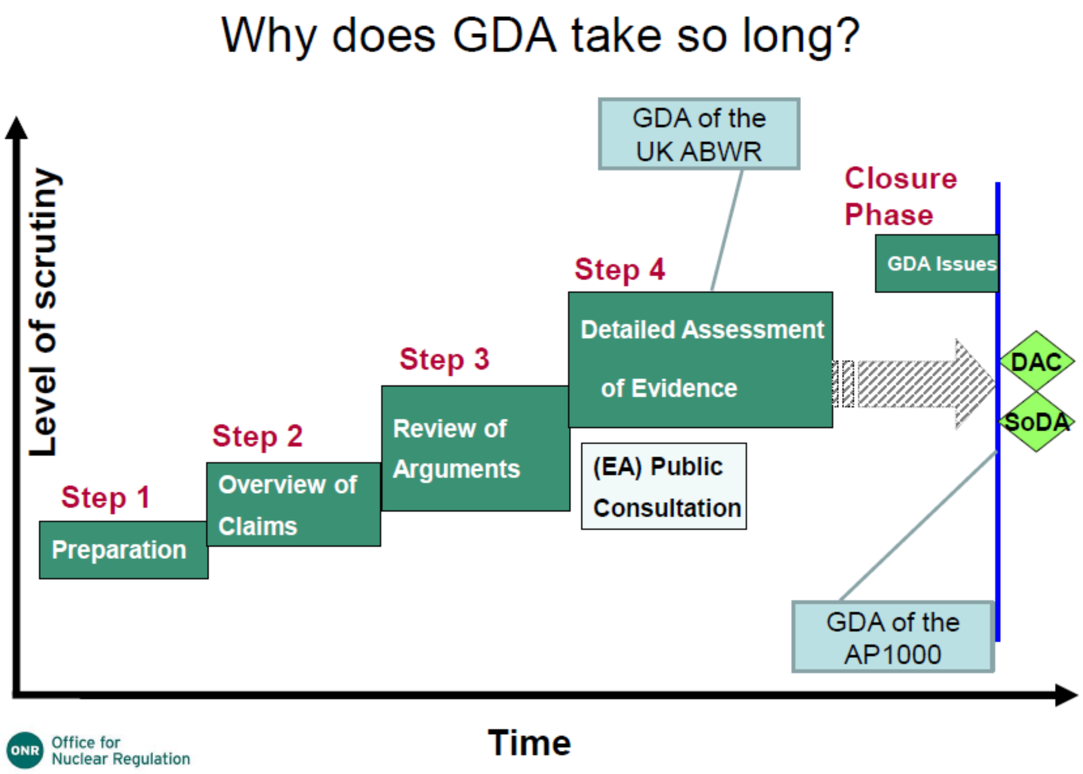
Generic Design Assessment (GDA)

GDA is a non-legally binding upfront, non-site specific, step-wise assessment of a generic reactor design undertaken by three joint regulators i.e. ONR, Environment Agency (EA) and Natural Resource Wales (NRW). The reason GDA is employed is because:

- It provides clear benefit in identifying and resolving key issues and design changes before the construction starts. This allows an effective and efficient use of regulatory resources, whilst reducing construction times and costs.
- It allows ONR to exercise an enabling approach i.e. able to give clarity on regulatory requirements, reducing project commercial risks while optimising the safety of the design.
- The process allows openness, transparency and public input, which results in public confidence in the project.

The GDA process takes around four years to complete for a new reactor design and involves a number of steps over this period:

1. Preparation
2. Overview of claims for safety
3. Review of arguments for safety
4. Detailed design, safety case and security evidence assessment and public consultation
5. Closure of GDA issues.



From step one to four the level of scrutiny i.e. the level of detailed technical assessment, increases. The successful GDA outcome for a reactor design is the awarding of a non-site specific Design Acceptance Confirmation (DAC) by ONR. The following reactors have completed the GDA process:

- UK European Pressurised Reactor (UK EPR) - Designed by EDF/Areva.
- Advanced Passive 1000 - AP1000® - Designed by Westinghouse

The reactors currently undergoing GDA are:

- UK Advanced Boiling Water Reactor (UK ABWR) - Designed by Hitachi-GE. Currently at stage 3.
- UK HPR1000 - Designed by China National Nuclear Corporation. Currently at stage 1

EA and NRW issue separate Statements of Design Acceptability (SoDA).

Licensing

Once a reactor design has successfully completed the GDA process e.g. UK EPR, the potential operator of the reactor i.e. EDF Energy must obtain a nuclear site licence from ONR to prescribe nuclear activities related to a reactor at a specific site. Once the nuclear site licence has been granted, the licensee must comply with the relevant provisions of the Nuclear Installations Act 1965 (NIA65) and all the conditions that ONR has attached to the licence. The licence has thirty six standard conditions whose compliance is enforced by ONR and is granted for an indefinite period, the licence can only be granted to a corporate body and is non-transferable.

Prior to granting a licence, ONR need to be satisfied that:

- The applicant's choice of site is suitable.
- That it understands the hazards and risks of activities it proposes to carry out.
- That it has a suitable schedule of safety submissions leading through to a Pre-Construction Safety Report (PCSR).
- The applicant has the organisational capability to lead and manage safety effectively.
- The applicant's governance arrangements, resources, competencies and management processes.

A full site-specific PCSR is not required for licencing but is expected to support permission for first nuclear island concrete. ONR's focus during licensing is on:

- How the licensee plans to develop the site-specific design and safety case and grow its capability.
- The 'GDA delta', this is the difference between the generic design and the site-specific design i.e. external hazards, civil engineering and fault studies.

Construction

During this phase, ONR's regulatory activity focuses on equipment procurement, design modification and pre-commissioning issues and the development of the licensee's organisation. ONR expects the licensee to provide a PCSR to support the start of nuclear safety related construction; as part of this the licensee can take credit for assessment work undertaken during GDA.

Regulatory control by ONR over construction, commissioning and operation is managed by a series of 'hold-points' whose criteria must be met by the potential operator before the next step in the process is undertaken.

Small Modular Reactors (SMR's)

Mike briefly discussed the regulation of SMR's. Regulatory activity would be broadly the same as for full scale reactors i.e. GDA, licensing, construction etc. however there might be scope for some activities to run in parallel e.g. licensing and site-specific assessments to expedite the whole process.

Some of the potential regulatory issues that ONR might face were mentioned, these were:

- Regulatory oversight of off-site modular construction.
- Potential for resource sharing between companies.
- Prospect of separate ownership of modules on a single site.
- Potential for multi-module operation by a small number of operators from a centralised facility.

Concluding Remarks

Mike concluded his presentation by stating that ONR faced a number of regulatory challenges at the same time as regulating nuclear new build i.e. the decommissioning of legacy facilities and the safe operation of existing nuclear facilities/power stations. That ONR has reorganised to focus on nuclear new build as a priority activity and that ONR has the capability and flexibility to meet all these challenges.

Questions and Answers

Following the presentation Mike answered several questions from the audience, some of which are listed below.

Q. How do ONR regulate the off-site production of important nuclear safety related components / equipment?

A. The responsibility for safety is with the licensee, so for example in the construction of Hinkley Point C the focus of regulation would be on NNB Generation Company (NNB GenCo). NNB GenCo would need to assure and demonstrate to ONR the quality of the nuclear safety related components / equipment, before they bring them onto site. ONR has the vires to inspect all the UK based supply chain. Internationally it is more difficult to inspect the supply chain, but ONR can collaborate with its regulatory international partners e.g. the French Nuclear Safety Authority (ASN) to determine the safety of components / equipment.

Q. Lessons learned from previous GDA's allow any new GDA's to proceed more efficiently, is the same true for the licencing phase?

A. There would be; the last time a new nuclear power station was built was Sizewell B, decades ago and lessons would inevitably be learned both by the licensee and ONR from all stages of the regulatory process and they would be incorporated into the GDA and licensing process.

Q. What would happen if there arose a conflict between two regulators e.g. hypothetically for example ONR and EA disagreeing over waste generated during decommissioning of the reactors?

A. There have been small issues that required discussion; but ONR works closely with both the EA and NRW to come to an agreed position. It was important that all regulators meet the 'Regulators' Code'.

Event – European Nuclear Young Generation Forum

Article by: Alfie O'Neill

This event, held in Manchester, was attended by the IOP NIG on the 15th June 2017.

The European Nuclear Young Generation Forum (ENYGF) brings together students and young professionals from across the European nuclear industry. This year the event was held in Manchester and hosed by the UK Nuclear Institute. The week-long programme included expert speakers, interactive workshops and varied technical tours to sites around the UK. On the Thursday of the week, an exhibition was held with approximately 60 companies, institutes and academic bodies represented, which the IOP NIG attended.

Heather Beaumont (Group Chair) and Alfie O'Neill represented the NIG, alongside staff from the IOP. Mingling with the attendees at the forum and other exhibitors we were able to advertise the group and its activities to a wide audience (and hopefully have some new members signing up too!).

Event – Nuclear Fusion, 60 Years on from ZETA by Chris Warrick (UKAEA), Kate Lancaster (York Plasma Institute), David Kingham (Tokamak Energy) and Ian Chapman (UKAEA)

Article by: Chris O'Leary

This seminar took place on 14 June 2017 at the University of Birmingham.

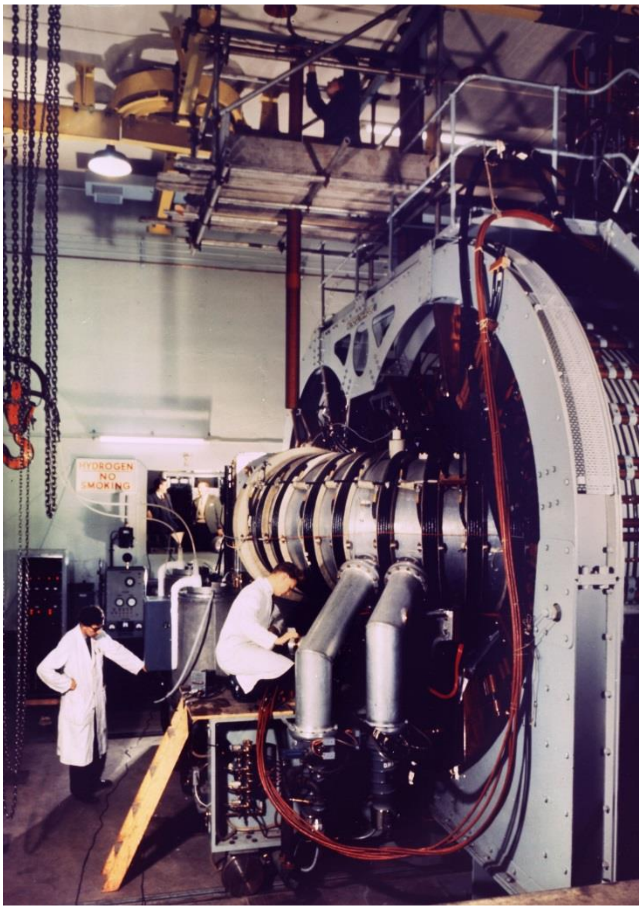
The event drew its title from the 60th anniversary of the Zero Energy Thermonuclear Apparatus (ZETA) fusion experiments, but was also intended to provide a high-level summary of the status of fusion research in the UK, with talks delivered by four leaders from that community. It marked something of a departure for the Nuclear Industry Group (NIG); most of our events seemed focussed towards the fission community. It's hoped more events from this sector can be accommodated in the future, as it's an area where there's a lot of scope for innovative physics.

Among the audience were three members of the committee: Chris O'Leary (Treasurer), Heather Beaumont (Chair) and Tzany Kokalova-Wheldon (seconded to NIG from the Nuclear Physics Group, for whom she is Chair). The event was held in collaboration with the Nuclear Physics, History of Physics and Plasma Physics Groups; the largest collaboration our group has been involved with since its inception.

Light refreshments were served before the first talk by Chris Warrick. Unfortunately, there were unresolvable problems with the audio-visual equipment in the lecture theatre and we had to move to another, starting 25 minutes late; though we managed to recover this by the end of the seminar.

60 Years on from ZETA – Chris Warrick, Head of Communications, UKAEA

Chris gave a wide-ranging, historical perspective on fusion research, starting with a discussion of the fusion processes of our nearest star, the sun. He then discussed the development of nuclear fusion research in the early twentieth century, taking-in the work on the Cockcroft-Walton accelerator at Cambridge in the 1930s; the 'pinch' experimental work by Peter Thonemann (who, incidentally, celebrated his 100th birthday on 3rd June this year) at the Clarendon Laboratory in Oxford and that of George Thomson and Alan Ware at Imperial College in the 1940s. This led to the work at Atomic Energy Research Establishment (AERE) Harwell.



ZETA

The fusion research at Harwell took place in 'Hangar 7' (it had been an RAF airfield) and was classified due to the parallel research into its application to weapons; this is the location where ZETA began construction. There was ongoing dialogue with the US and a sharing of information on each other's efforts at this time.

Chris spoke about the huge interest generated by the visit of Soviet Premier [Nikita Krushcev](#) and the famous nuclear physicist [Igor Kurchatov](#) in 1956 to Harwell, noting that Blackwell's bookshop in Oxford changed its signage to Russian in celebration of the event and permission had to be given at the Prime Ministerial level by Churchill! There was much public focus on the UK's energy research programmes at this time, not just for ZETA.

During the visit, Kurchatov spoke openly about the Soviet fusion programme and, from this, it was clear that they were at least level with UK and US efforts; he was keen to discuss their research and share what they were doing with the British researchers. The visit helped to declassify the work in the UK pertaining to controlled fusion research which was moved to another near-by site at Culham. It also led to a team of five scientists from Culham spending a six-month period in the Russian fusion research facility near Moscow, to help set up laser deflection apparatus. This mandated five Russians spending the same period in the UK.

Chris remarked on the large number people smoking pipes in the shots of ZETA and researchers, contrasting it with today's health and safety regulations.

Chris highlighted the lack of diagnostic capability for ZETA and its counterparts, and how this made it far more difficult for the scientists working on the system compared to their modern counterparts, who can use high performance computers and full instrumentation.

Chris showed a video titled 'Taming the H Bomb (1958)' from the British Pathé News site at http://www.britishpathe.com/search/query/zeta/recordcategories/Science++Technology

As an aside, he noted that the Manchester Science Museum has exhibits from the ZETA programme.

Chris went on to discuss some alternative approaches, such as the Princeton Stellerator 8 built by Lyman Spitzer in the 1950s, and the work at Lawrence Livermore National Laboratory 'magnetic mirrors'. He later compared the tokamak, which are "easy to build but a beast to operate", to stellerators, for which the opposite is true.

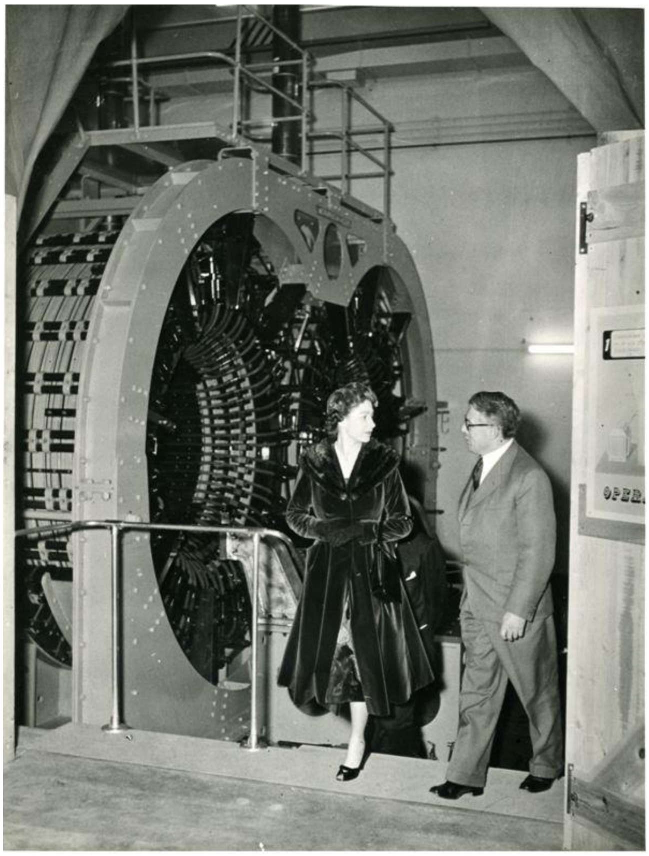


Figure Queen Elizabeth II visits ZETA

An IAEA conference, 'Atoms for Peace' was held in 1965 at the opening of the Culham Laboratory, during which Spitzer discussed the drawbacks of the various approaches, and the drawbacks with each. The most promising work seemed to be that of Lev Artsimovich from the USSR – who described encouraging results from a so-called 'Toroidál'naya kámera s magnítnymi katúškami' or Tokamak. The toroidal field was much (by a factor of 500) larger than in classical 'pinch' devices.

Experiments on tokamaks took place throughout the 1960s and 1970s, and the decision was eventually made by the European Commission to construct a European tokamak called Joint European Torus, or JET, that would be 100 times bigger than existing devices; one of the major drivers for this being the 1970s oil crisis. The design work was carried out at Culham by an international team but the choice of site and director (of a different nationality) took many years and reached a high political level.

The choice was eventually between Culham and a site near Garching in Germany; Chris drew a connection between the decision to site JET at Culham and the help the UK gave to the

German government, via the SAS, in solving the Lufthansa Flight 181 hijacking by 'Popular Front for the Liberation of Palestine' in 1977.

In discussing the construction of JET, Chris mentioned the construction workers claims that they saw ghosts on the old airfield. He also discussed the major differences between JET and the US Tokamak Fusion Test Reactor (TFTR) experiment at Princeton. The European design used a D-shaped toroid whereas the US adopted a spherical design; Chris discussed why the former was seen as being superior.

Chris also discussed the 'fortuitous' discovery of H-mode by Fritz Wagner in 1982 at Garching; this was to have a big impact on the development of fusion research.

Chris concluded his talk by noting that there are more than 50 tokamaks operating worldwide. The next generation experiment, the International Thermonuclear Experimental Reactor or ITER, was conceived as early as 1985, but site selection did not take place until 2006, with first plasma expected in 2025.

In the question and answer session at the end of Chris' talk, Professor John Allen, of the University of Oxford, noted that he had been present for the Krushcev & Kurchatov visit, and sought to clear up a misunderstanding about the publicity surrounding the claims that fusion had taken place. He noted that the experimental team did not claim a thermonuclear reaction had taken place, adding that British newspapers encouraged John Cockcroft to confirm fusion had taken place, who eventually stated he was 90% certain fusion had taken place. Other papers took this story up – there was incredible press interest and even a BBC outside broadcast at the laboratory, possibly due to the impact the work could have on the nation's morale. Chris wondered if there had also been pressure from the US to publish, in light of the recent Sputnik success enjoyed by the Russians.

Professor Allen further noted that, for the Kurchatov lecture, he and the other scientists were instructed by Mr Fry, the Division head, that: "You must not, by your questions, give him any idea of what you are working on, or what you are thinking about doing next".

Inertial Confinement Fusion – Kate Lancaster, Research Fellow for Innovation and Impact, York Plasma Institute

Kate gave what she described as a 'whistle-stop tour' of Inertial Confinement Fusion (ICF).
Kate discussed the pioneering work of an early leader in the field, John Nuckolls of Lawrence Livermore National Laboratory (LLNL) whom she described as, essentially, the father of ICF. The work was declassified in the 1970s, around the time of the first indirect drive laser implosion experiments. Prior to the advent of laser technology, it was hard to get the MJ of energy required into a 'tiny space'.

Kate spent some time explaining how ICF works; high-energy lasers are fired at pinhead-sized fuel pellets which are designed to implode. Shock waves cause compression, heating, and finally thermonuclear fusion. This process needs to happen multiple times per second to maintain nuclear fusion; the same order of magnitude as the firing of a cylinder in a car engine.

She highlighted that ICF, like MCF, is inherently lossy, due to radiation effects such as Bremsstrahlung electrons. The energy gain must be sufficient to overcome these losses. Lasers are currently quite inefficient – less than 1%, though hopes are that this can be raised to 10 to 15% in the future. Fuel size is restricted, e.g. to tens of milligrams, so that the reactor doesn't explode. There is also the Rayleigh-Taylor instability to overcome.

Kate discussed the work of the National Ignition Facility (NIF), at LLNL, which she described as the state-of-the-art for ICF, and that many physics and engineering challenges remain. For example, the NIF can only 'fire' a few times per day, but for a workable fusion power plant this would need to increase to multiple times per second. The pioneering work of the DIPOLE project in the UK, on diode-pumped solid-state lasers (which are more efficient), may provide a solution to this problem.

She concluded by noting that many technological challenges, such as tritium breeding and materials in extreme conditions are similar to those faced by MCF.

Compact Spherical Tokamaks – David Kingham, Chief Executive, Tokamak Energy

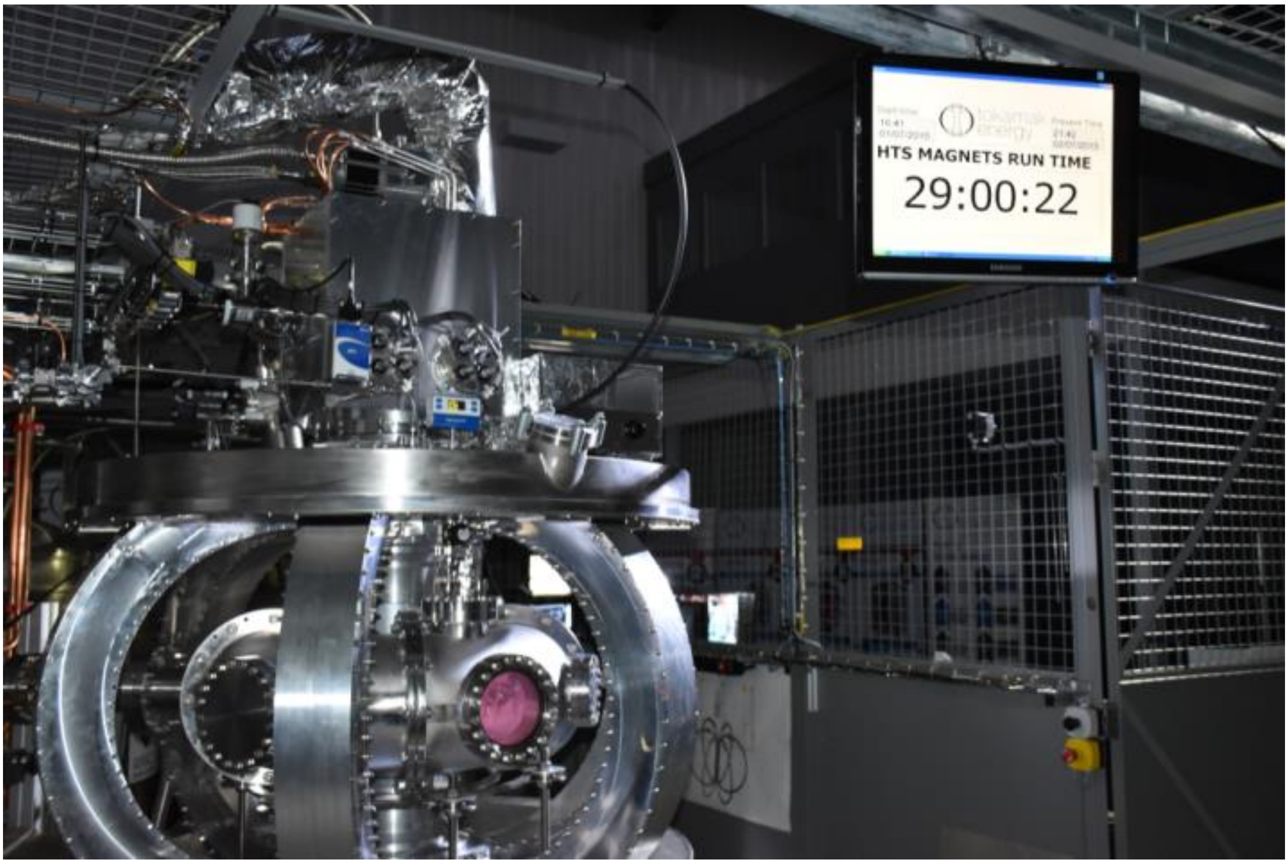
David Kingham stated that his talk would be mainly about innovation strategy and started by suggesting there is a need to get fusion power online by 2050 to meet 'deep decarbonisation' climate change targets. He acknowledged that renewables, like wind and solar, have roles to play and added that fission can help; but the latter is not acceptable in all parts of the world at all times.

David posed the question of whether it was too early for private research into fusion and then answered it by stating that the strong challenges the field faces can only be solved not only through collaboration, but also by competition between different approaches.

He noted that private investors are getting seriously interested in fusion power research, with hundreds of millions of dollars being invested each year. He highlighted that public funding was focussed on tokamaks but private capital currently was not; in fact, Tokamak Energy is the only private company developing tokamaks.

David discussed the advantages of spherical tokamaks relative to, more conventional, 'high aspect-ratio devices' such as JET at Culham in the UK. It is his conviction that the combination of spherical tokamak technology with High Temperature Superconducting (HTS) magnets offers the possibility of constructing devices of relatively low power and small size, yet with high performance (high fusion power gain). The small size could offer a faster route to fusion power, and then to widespread commercial deployment, than the larger devices.

David spent some time discussing the work of Tokamak Energy, including the early history of the



ST25HTS – a small tokamak with all its magnets made of high temperature superconductor

pioneering START spherical tokamak at Culham being built from spare parts. An investment of £20M in Tokamak Energy to date had led to two prototypes being completed, with a third device at an early stage of commissioning and a number of patents being filed, particular in superconducting magnet technology. Over the next three years, the company aims to demonstrate high performance in a prototype compact spherical tokamak, i.e. getting within an order of magnitude to energy breakeven conditions and to demonstrate that there are no major showstoppers in using compact spherical tokamaks with HTS magnets for economically viable fusion power.

David discussed the timeliness of private investment in fusion, drawing parallels to private ventures tackling challenges previously assumed to be the realm of government ventures like Virgin Galactic and Space X, suggesting that the private sector now has a greater appetite for risk in scientific projects than Western governments. He considered this is good news for fusion which, he felt, over previous decades had become large, political and cumbersome. In contrast, he felt that private investment allows smaller, agile companies to try different approaches and make new inroads into ‘an old problem’. He quoted scientific journalist Dan Cleary, who had come to the conclusion that avoiding mono-culture in novel research was crucial, i.e. “… *try more things in parallel*”.

David spoke about the ‘Breakthrough Energy Coalition’ and the newly announced ‘Breakthrough Energy Ventures’ (BEV), a group of billionaires investing a total of $1bn into ground-breaking new energy ventures, fusion being one of their list of 55 technical area for consideration. They are particularly interested due to the deep challenge of decarbonisation facing the world.

After David’s talk, there was a question from audience about battery storage, i.e. if that were perfected would nuclear energy be needed at all. David responded by stating that renewables and battery storage have made great progress towards the ‘easy’ climate change targets; but the ‘hard’ targets of zero carbon or negative carbon by 2050 would need fusion power. This matched BEV’s opinion that several technologies will be needed.

David further noted that the parallel development of Small Modular Reactor fission power plants would be useful to development the downstream power generation for fusion systems.

Future Path for Fusion – Ian Chapman, Chief Executive Officer, UKAEA

Professor Ian Chapman started off by discussing fusion in the context of a direct replacement for high carbon energy sources, providing a baseline to the fluctuating profile from renewables. He mentioned the global picture, where growing economies were driving a bigger push for fusion; noting that the South Korean constitution aims for delivery of fusion power by 2037.

Ian went on to discuss some of the recent historical challenges faced by fusion, such as the stagnation in the 1990s and 2000s caused by the lack of a decision on the ‘go-ahead’ for ITER. He noted that ITER was currently two-times over budget and two-times over schedule, and then spent some time discussing the economics of nuclear power stations in general.

Ian continued his discussion on ITER within the framework of if being ‘proof-of-concept’ political project, reliant on seven partner nations, rather than simply an engineering project. He mentioned examples of where decisions had been made on this basis, e.g. the toroidal field coils are produced in different countries despite being of the same design. This has led to a complex supply chain, necessitating involvement from lawyers; this contributed half the reason for project delays and going over budget.

He went on to discuss where the costs lay in the project and routes to drive them down, noting that UKAEA had been busy in the last twenty years working on a wall replacement and a redesign of the Mega Amp Spherical Tokamak (MAST). He noted that a smaller machine needs a more advanced exhaust system, and then discussed the new exhaust panel, representing four years of work, that had been designed the UKAEA team. He suggested that the upgraded MAST would start operating again before Christmas and that new records would be aimed for over the next few years.

He also discussed some new capabilities developed at Culham, such as materials testing for high-radiation environment, i.e. up to 4 TBq, and the RACE project for remote applications using robotics.

Ian discussed the role of UK industry in the delivery fusion power, noting that UKAEA is too small to build thousands of reactors. Therefore, there is a need to transfer skills from UKAEA into industry through upskilling and other knowledge transfer activities. He encouraged industry to get involved in fusion and expressed a wish to see greater levels of engagement.

He went on to discuss the predicted costs of fusion power stations and how to reduce this; the role of MAST-U; the importance of availability in commercial power generation and the requirement to maintain a consistent power output.

He finished by stating that all of the physics for fusions research is not currently understood and reiterated that ITER is fundamentally a plasma experiment.

Picture left to right: Professor John Allen; Dr David Kingham; Dr Kate Lancaster; and Professor Ian Chapman.

Summary

After the final talk, more refreshments, comprising wine and cake, were provided by the University of Birmingham. All the days' talks were excellent and we received a lot of positive feedback from attendees.

Note that the presentations from the first three talks are available at the IOP website here: http://bit.ly/2wa28JN

IOP Materials and Characterisation Group Meetings

Article by: Paul Binks of the IOP Materials and Characterisation Group

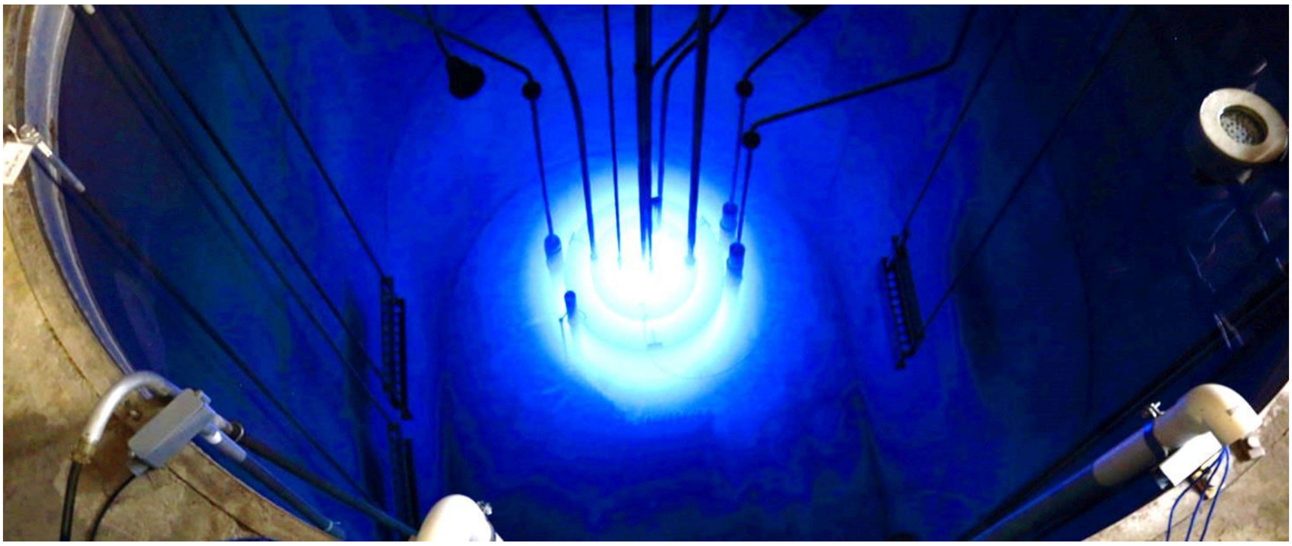
The Materials and Characterisation Group aims to foster activities in the fields of materials and material characterisation within the IOP. Our large group membership includes academic, industrial and governmental research organisations, both nationally and internationally based, a clear reflection on the breadth of the (often multidisciplinary) field.

Broadly speaking our interests cover:

- The properties and application of materials, old and new
- The manufacture, modification and extraction of materials
- All types of material characterisation including physical, electrical, optical and elemental
- Development of materials characterisation techniques and applications

For more info please see the group webpage at http://bit.ly/2gIyPYO

Characterisation of Materials used in Nuclear Environments - IOP Portland Place, London, 4 July 2017



Characterisation of Materials used in Nuclear Environments was a one day meeting held on Monday 4th July 2017 at the IOP Portland Place, London. This event was organised by the Materials and Characterisation Group and sponsored by the IOP Nuclear Industry Group and AWE.

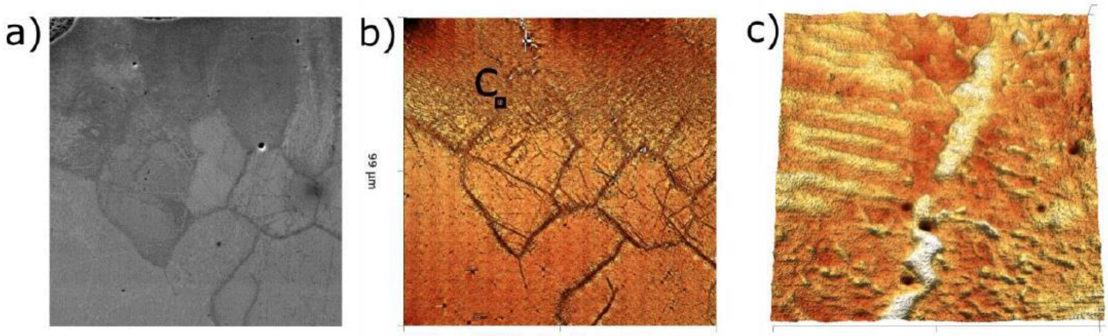
The first speaker was Mrs Helen Hulme (Amec Foster Wheeler) who discussed the corrosion behaviour of zirconium alloys. Zirconium alloys are used as nuclear fuel cladding materials in water cooled reactors due to their favourable corrosion resistance and hydrogen pick-up properties in nuclear reactor conditions. However, the corrosion behaviour is strongly dependent on the alloying elements present within the material and corrosion environment the material is subjected to. Work conducted in the Core Materials team at Amec Foster Wheeler focuses on extensive corrosion testing over a number of years to produce test specimens which have then been characterised using a range of techniques with the aim of understanding more about the physical mechanisms of zirconium alloy corrosion in order to aid corrosion predictions required to justify the safe operation of a nuclear reactor. The presentation focused on electron microscopy techniques such as Scanning Electron Microscopy (SEM) and Scanning Transmission Electron Microscopy (STEM) equipped with Electron Energy Loss Spectroscopy (EELS) which have been used to study the oxide microstructure formed under different corrosion environments. Results from this characterisation provide information on what effect the corrosion environment has on the developing oxide and metal microstructures and subsequent changes that occur during the transitional behaviour of oxide growth.

Professor Michael Preuss from the University of Manchester presented results of detailed studies using a multiscale characterisation approach by employing diffraction and novel electron microscopy techniques. In order to develop a better understanding of the evolution of damage and micro-segregation, proton as well as neutron irradiated zirconium alloys have been investigated using STEM-based ultrahigh resolution EDX spectrum imaging and synchrotron x-ray diffraction. These investigations have been carried out on two types of zirconium alloys, Zircaloys (containing no Nb) and Zr-Nb type alloys. These studies have provided a detailed picture and have enabled quantitative analysis of the evolution of <a> and <c+a> dislocation loops as a function of dpa. In addition, ultrahigh resolution EDX mapping provides new insight in the possible role of micro-segregation and the formation of nano-precipitates or nano-clusters on dislocation loop formation. These new observations are interpreted in the view of dimensional instabilities observed for zirconium alloys, particularly growth, as well as the potential impact on corrosion and hydrogen pick-up.

Dr Paul Styman from the National Nuclear Laboratory presented work on Support from Multiple Characterisation and Modelling Techniques in Predicting Reactor Pressure Vessel (RPV) Embrittlement. The progressive embrittlement of the steel RPV is a life-limiting factor in the majority of Gen II and Gen III commercial nuclear power plant. It develops from the clustering of point defects into hardening centres and the segregation of solutes to grain boundaries. The hardening centres are on the nanometre scale, but no single microstructural characterisation techniques is able to characterise the hardening centres and segregants completely. Paul illustrated how multiple techniques have been applied to characterise the hardening features, their development and interactions, and how understanding of microstructural development has underpinned the formulation of the embrittlement trend curves used to predict RPV structural integrity. Advances in experimental techniques and the contribution from mechanistic modelling were discussed. Examples were given on the information being acquired to support current plant lifetime extension and the 60-80 year planned operational lives of Gen III+ reactors.

The final talk of the morning was on understanding the corrosion of uranium by using Atom Probe Tomography (APT). This was given by Ms Camille Coe from AWE. Understanding the corrosion of uranium is important for its safe, long-term storage. Uranium metal corrodes rapidly in air, but the exact mechanism remains subject to debate. Camille used APT to investigate the surface microstructure of metallic depleted uranium specimens following polishing and exposure to moist air. A complex, corrugated metal-oxide interface was observed, with approximately 60 at % oxygen content within the oxide. Interestingly, a very thin (~5 nm) interfacial layer of uranium hydride was observed at the oxide-metal interface. Exposure to deuterated water vapour produced an equivalent deuteride signal at the metal-oxide interface, confirming the hydride as originating via the water vapour oxidation mechanism. Hydroxide ions were detected uniformly throughout the oxide, yet showed reduced prominence at the metal interface. Camille's results support a proposed mechanism for the oxidation of uranium in water vapour environments where the transport of hydroxyl species and the formation of hydride are key to understanding the observed behaviour. Niobium is added to uranium to increase its corrosion resistance. The actual mechanism behind this enhanced resistance is uncertain with two proposed hypotheses: formation of a layer enriched in niobium or the formation of a mixed oxide. APT was used to investigate the surface microstructure of UNb3 and UNb6 specimens following polishing and exposure to moist air. Analysis of the APT data has provided fundamental information on the structure of these alloys that directly relate to their corrosion properties. Both alloys showed some phase separation, displaying niobium rich and depleted regions. This separation was most evident with the UNb6 specimens. This phase separation is most likely due to ageing with the UNb6 material being significantly older than the UNb3. Any phase separation due to ageing will affect the properties of the material, such as an increase in strength but a decrease in ductility and corrosion resistance.

After lunch Dr Oliver Payton from the University of Bristol presented a talk on High-Speed Atomic Force Microscope (HS-AFM). Bristol are using this new microscope as a predictive and diagnostic tool in the field of material science and material failure analysis. The HS-AFM is capable of mapping out nano and micro structures across millimetre sized areas in a matter of minutes, a task that would take a conventional AFM over a year to carry out. The macro sized physical properties of a material are often a product of the nano sized structures within. In order to better predict the lifespan of a piece of plant or storage apparatus it is vital to know how these nanostructures are affected by the harsh and unique environments to which they are exposed. It is also important when designing the next generation of materials for the nuclear industry to know how the nano and micro structure of these materials is affected by the upscaling in manufacturing. The nanostructures of interest may be implanted into the material deliberately, such as the use of nanoparticles in ODS steel; however, the nanostructures might also be nano-fractures, secondary inclusions or any other inhomogeneities in the components of the new materials. There is currently no tool to map and characterise the distributions of these nanostructures across macro sized areas with spatial information. Many of the existing techniques such as SEM are sensitive only to the larger structures, while characterisation tools such as transmission electron microscopes have the necessary resolution but are limited to mapping small sample areas. Oliver presented the current state of the art of HS-AFM technology and demonstrated how at the University of Bristol they have used this new tool on materials relevant to the nuclear industry, such as type 316 steel, 9-chrome steel, ODS steel, and actinide material.



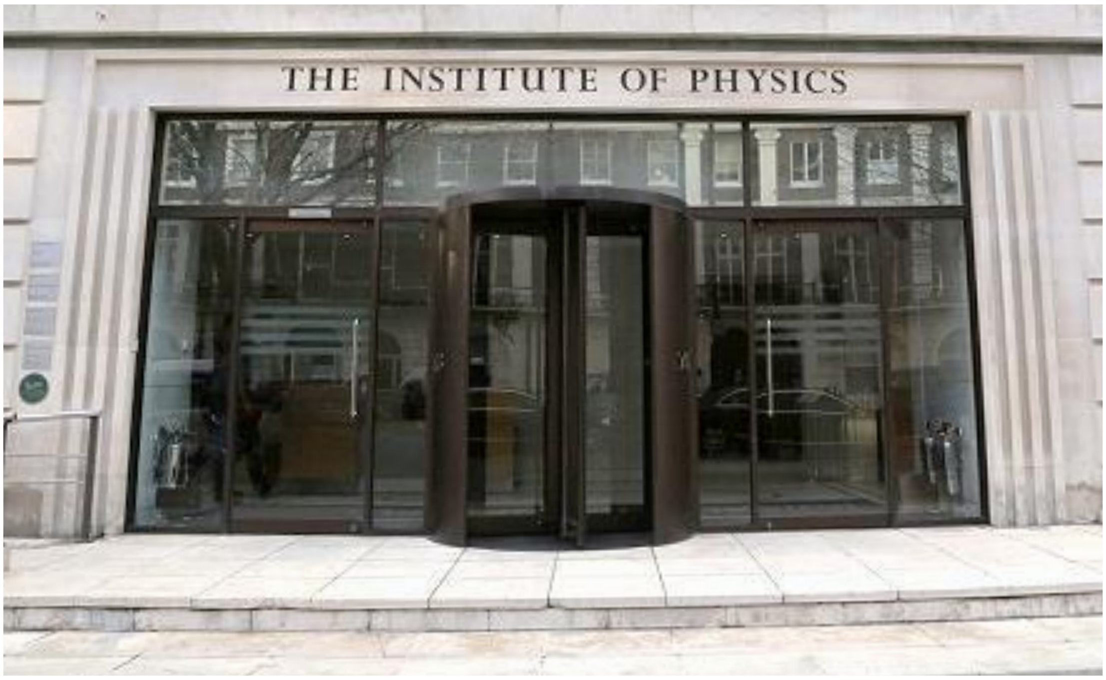
This figure shows a section of type 316 steel which has been heavily carburised along its top edge. a) shows the SEM image of the 100,000 μm2 area, b) shows the HS-AFM topography map of the same sample, and c) shows a blown up section of the highlighted region in b) indicating the high resolution achievable using HS-AFM. A grain boundary and carbides, some measuring only 10 nm in size, can clearly be seen in c).

The next talk was presented by Dr Christopher Hardie from Culham Centre for Fusion Energy on Understanding the effect of radiation damage on mechanical properties. Due to the harsh environment within nuclear fusion and fission reactors, degradation of structural materials occurs over their lifetime. Investigating the effect irradiation has on materials is limited to a few techniques which impose different challenges. Irradiation by charged particles offers a relatively fast, cost effective and for the most part non-radioactive method of irradiating materials, however charged particles have far smaller stopping distances in materials and the volume of irradiated material is limited. Unlike many characterisation techniques which require inherently small volumes of material, the limited volume of irradiated material presents a significant challenge for the measurement of mechanical properties. Chris presented the challenges, limitations and pitfalls of using nano-indentation and micro-mechanical testing for testing ion implanted layers. Recent efforts at UKAEA was shown, which included the use of spherical indentation and high resolution strain mapping from Transmission Kikuchi Diffraction (TKD) analysis. The research capabilities within the newly established Materials Research Facility at UKAEA, funded by the National Nuclear User Facility and the Henry Royce Institute, were described.

After an afternoon coffee break, Dr Christopher Mallinson (Fraser-Nash) presented his PhD work which he did at the University of Surrey on the localised corrosion of beryllium: a multi technique approach to study the role of second phase particles in pitting corrosion. Chris began by stating beryllium is a metal with a number of niche applications including: x-ray windows, space telescope mirrors and as cladding material in nuclear reactors. It is similar to aluminium as it is passivated by a thin native oxide layer which makes it susceptible to corrosion in the form of pitting. Pits are believed to be associated with sites of heterogeneity in the surface oxide such as second phase particles. Second phase particle compositions include: AlFeBe4, Ti3Si, BeO, elemental silicon, Be2C and Al2O3. The particles range in size from ~0.5 µm – 20 µm and so high spatial resolution techniques are required to investigate the corrosion mechanisms associated with them. A combination of techniques that have recently been utilised to provide new information about the corrosion process. These include: scanning Kelvin probe force microscopy, Auger electron spectroscopy and energy/wavelength dispersive X-ray spectroscopy.

The meeting concluded with Dr Vivian Tong from Imperial College London who discussed her work on Formation of large 'blocky alpha' grains in Zircaloy-4. Zircaloy-4 is in nuclear reactors in the form of thin-walled fuel rod cladding tubes. Maintaining a fine grain size is important to withstand the large thermal, mechanical and irradiation stresses in operation. Under certain conditions, very large grains, or blocky alpha, form within the small grained matrix, which is undesirable for structural integrity of the fuel rod cladding. Understanding the mechanism by which blocky alpha nucleates and grows is essential for both optimising manufacturing processes and understanding in-service performance. In this work, a strain-anneal method for consistently producing blocky alpha grains has been developed. It was found that grain size after annealing is dependent on the applied strain, and the critical strain required for grain growth is temperature dependent. The grain growth kinetics have also been studied, and a mechanism for blocky alpha formation was proposed based on these results. Understanding blocky alpha formation in zirconium alloys will enable manufacturers to avoid certain strain paths and temperatures in order to avoid blocky alpha e.g. during the pilgering process in tube manufacture, and also allow the long term microstructural stability of Zr in nuclear reactors to be better understood and potentially optimised.

The understanding of the performance of materials is vital for justification of next generation fission reactor plant design, plant lifetime extension of current operating reactors as well as the development of fusion reactors. High-resolution characterisation techniques have played an important role in the understanding of material degradation in nuclear environments and their vital role in providing scientists with information to aid this understanding will continue into the future. Materials in reactor plants are exposed to extreme environments such as aggressive water chemistries, high temperatures and pressures as well high radiation damage. This conference gave an insight into the study and current mechanistic understanding of various reactor components corrosion and degradation as well as the techniques that are employed to aid this understanding.



The IOP, Portland Palce, London

"Brexatom" – the implications of the withdrawal for the UK from the Euratom Treaty.

Article by: Heather Beaumont.

In February this year as part of the Brexit process the UK government announced its intention to pull out of the Euratom Treaty. This was set out in the explanatory notes that accompanied the Article 50 bill published by the government in late January and further details were provided in the white paper, published in early February. The prime minister's letter to the President of the European Council Donald Tusk triggering Article 50 in March confirmed the intention to leave Euratom alongside the EU.

Policy Brief | June 2017

The UK and the European Atomic Energy Community (Euratom)

The Institute of Physics is a leading scientific membership society working to advance physics for the benefit of all.

We have a worldwide membership, from enthusiastic amateurs to those at the top of their fields in academia, business, education and government.

Our purpose is to gather, inspire, guide, represent and celebrate all who share a passion for physics. And, in our role as a charity, we're here to ensure that physics delivers on its exceptional potential to benefit society.

This document provides background on Euratom and its functions in the UK. It highlights our concerns and recommendations for the future of the nuclear industry should the UK withdraw from Euratom.

To ensure a safe and secure future for nuclear energy production and research, if the UK withdraws from Euratom we recommend that the UK government:

- Ensures transitional arrangements for nuclear safeguarding, trade and funding are in place until the UK–EU negotiations are complete. These efforts should involve open discussion with the wider community, including industry.
- Establishes new UK safeguarding agreements that are in line with International Atomic Energy Agency (IAEA) conventions and standards so that trade of nuclear material, including medical radioisotopes, can continue without interruption.
- Retains membership of the European Observatory of medical radioisotopes and continues to work with Euratom and global partners to mitigate any future shortages of medical radioisotopes.
- Assembles new bilateral and multilateral cooperation agreements with Euratom and other key countries before the UK leaves Euratom.
- Guarantees funding for Euratom-related nuclear research projects, including the Joint European Torus and MAST-U, and continued UK involvement with ITER.

Background

The peaceful use of nuclear energy within the EU is governed by the 1957 treaty that established the European Atomic Energy Community (Euratom). While Euratom is a separate legal entity from the EU, it is governed by the EU's institutions: the European Commission deals with nuclear safety, nuclear safeguards and nuclear security. Currently, its only full members are EU countries. Euratom also has a range of bilateral and multilateral arrangements on nuclear R&D co-operation with other countries including Argentina, Canada, China, Japan and the USA.

According to the treaty, the specific tasks of Euratom are to:

- Promote research and ensure the dissemination of technical information.
- Establish uniform safety standards to protect the health of workers and of the general public, and ensure that they are applied.
- Facilitate investment and ensure the establishment of the basic installations necessary for the development of nuclear energy in the EU.
- Ensure that all users in the EU receive a regular and equitable supply of ores and nuclear fuels.

IOP Institute of Physics

This decision has potentially wide ranging implications for the UK nuclear industry. There have been many articles in the nuclear related press and all the main nuclear industry bodies have published statements expressing their concerns and setting out the potential impact on the industry. I am sure that many of you have been watching this with great interest as have the NIG committee. The key issues can be categorised in into four areas: safeguarding issues, trade of nuclear materials, movement of nuclear services and expertise, and research in nuclear fission and fusion. As part of their role as a leading scientific society the IOP have also published a policy brief outlining the main issues and the members of the NIG committee were privileged to participate in the IOP Policy Group, which has helped to inform the IOP and input into the brief. You can find a copy of the IOP Policy Briefing here: http://bit.ly/2gN69Sc

On 11th July 2017 the House of Lords Energy and Environment Sub-committee launched an inquiry into Brexit and Energy security. IOP have also submitted a response to this enquiry based around the policy briefing. The relevant webpage for the consultation can be found here: http://bit.ly/2ua2UJo

The key questions being explored by the committee are:

- What are the implications of the UK's withdrawal from the EU for the UK's energy security?
- Could, or should, the UK stay in the Internal Energy Market (IEM) post-Brexit? If not, what should be the priorities for continued co-operation with the EU?
- What will be the effect of Brexit on UK-EU energy interconnection?
- What EU funding is used in relation to energy infrastructure and research? Can it be effectively replaced by existing UK schemes?
- What measures would allow the continuation of the Integrated Single Energy Market in Ireland after Brexit?
- What are the implications of the UK's withdrawal from Euratom? Will it affect the UK's security of supply?
- What can the UK learn from other non-EU countries' experience of trading energy with the EU?

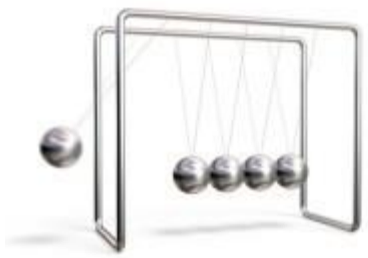
The IOP submission to this inquiry along with all those from other organisations will appear on-line in due course. We are sure that as with all the other Brexit related issues that are dominating the UK news that "Brexatom" will also continue to be scrutinised and as an industry we need to keep lobbying government to ensure that our issues are addressed in any negotiations.

IOP Continued Professional Development

The IOP offers a range of Continued Professional Development tools to its members, information can be found online at http://bit.ly/2w9LNEU

Life-long learning is key to career success. The IOP offers its members the chance to make the most of themselves through a range of professional development opportunities, and support employers to offer the very best in training.
IOP tools and resources range from advice on becoming a chartered physicist to online learning you can take advantage of whenever it suits you.

- Professional development workshops - find out about getting chartered or mentoring at our short evening workshops
- Professional helpsheets – a free resource to members helping you manage your own professional development
- Online learning – soft skills courses you can take anytime and anywhere
- MyCareerPath – the unique online physics career planner tailored around you
- Outreach workshops – boost your skills as a science communicator
- Professional development articles – articles on professional development that you might find useful
- Mentoring – receive support and guidance from experienced members



The IOP also offer accreditation of company training schemes and guidance to employers.

NIG Members Survey

We'd like to hear from you! In order to help everyone in the NIG get the most from their membership we would like to know what it is you'd like to see the committee and group doing. This will help us align the groups focus and events with the needs and expectations of our members. We're also open to feedback on how to increase attendance at meetings and events.

A survey will be coming out via email shortly to give you the opportunity to tell us what we do well, what we could do better and what you'd like to see in the coming years, so watch this space.

Joint Membership with the Nuclear Institute

The IOP have teamed up with the Nuclear Institute to present a new membership offer – you can receive 25% off your IOP membership fee if you are a member of the Nuclear Institute.

For more information on the Nuclear Institute see www.nuclearinst.com

Nuclear Decommissioning PhD Bursaries

Did you know… the NDA annually seeks applications for PhD research proposals related to nuclear decommissioning to a total of £500,000! They are seeking proposals which support the NDA mission to deliver safe, sustainable and publicly acceptable solutions to the challenge of decommissioning and clean-up of the UK's civil nuclear legacy.

Applications for the annual bursary scheme are invited from:

- UK academic institutions for PhD projects
- sub-contractors, including Small and Medium-sized Enterprises (SMEs) seeking 'top-up' funding for CASE awards and EngDocs

The relevant themes are:

1. characterisation
2. waste packaging and storage
3. land quality
4. decommissioning
5. spent fuel and nuclear material
6. open criteria and collaboration with US research organisations

NDA
Nuclear Decommissioning Authority

Eligibility will cover PhD projects involving universities or sub-contractors where the bursary is used as a grant top-up to access national facilities for research involving the handling of radioactive materials.

The next opportunity to submit a proposal opens in September 2017, for more information see the website here: http://bit.ly/2xcZZlq

Future Nuclear Industry Group Newsletters

In order to reduce the printing and distribution costs of delivering our annual newsletter the IOP NIG committee have decided to move to a opt-in approach for receiving paper copies of our newsletter in future. This will enable us to spend more of our funding received from the IOP organising events and activities for our members, and reduce our environmental impact in printing and posting copies to all our members.

As such, if you wish to continue receiving **paper** copies of the NIG Newsletter from 2018 onwards please contact Alfie O'Neill at alfie.oneill@physics.org, or writing to Alfie O'Neill, National Nuclear Laboratory, Preston Laboratory, Salwick, Preston, PR4 0XY. Please remember to include your postal address so we know where to send the newsletter!

All other members will in future receive electronic copies of our newsletter to their IOP registered email address.

Letters to the Group

The NIG welcomes letters from its members, so please get in touch with us if you attended one of our events and it sparked an idea, you have been involved in a particularly interesting project or have any other thoughts which might be of interest to the rest of the group!

Please submit any articles and accompanying photographs or pictures to alfie.oneill@physics.org.

Fast Reactor Work at Culcheth - Piers Mason *BSc, MBA, MInstP, MSaRS, AMRAeS*

I was grateful for the review by Brian Kehoe of the development of fast reactor technology at Culcheth. I have close family connections to both the development of the DFR fuel, and also to the development of its manufacturing plant, eventually sited in building D1201 at Dounreay. I am, I regret to say, poorly informed about this phase of fast reactor development and I learned much from Brian's note. Could I add to what he wrote about the development of the Prototype Fast Reactor (PFR), as he dealt with it in 3 or 4 lines and not too favourably.

The idea of a nuclear reactor that could breed more fuel than it consumed was first conceived by Leo Szilard in 1943, when uranium was scarce and it was not clear that better supplies of it could be obtained. This led directly to the development of the UK's fast reactor programme and the developments of fast reactor technology at Dounreay. DFR as described by Brian Kehoe was the first fast reactor in the world to generate electricity. Its successor, PFR, was conceived for several purposes:

- To develop the core physics and dynamics for a large scale fast reactor core, powered by MOX fuel and with liquid sodium as the heat transfer medium.
- To develop the heat transfer systems on a near industrial scale so as to generate steam to run a turbo-generator.
- To develop the MOX fuel. It is worth noting on this point that the design of the fuel used in the PFR was that intended for the follow-on Commercial Fast Reactor (CFR).

The building of the PFR suffered from a problem familiar to many who have worked on major publicly funded projects. This is the ease with which the provider of funds, HM Treasury, will postpone expenditure today at the expense of greater expenditure tomorrow.

Liquid sodium and water/steam do not mix easily. The materials and requirements for welded joints wanted by the UKAEA for the PFR steam generators proved to be too expensive for the Treasury and a compromise cheaper installation was made. Unsurprisingly, the early operations of the PFR were dogged by persistent problems with the steam generators. This left the UKAEA making the best it could of the situation.

PFR's operations can thus be divided into 2 phases. Phase 1 proved the core physics and dynamics. The excellent inherent safety of an unpressurised pool primary circuit was demonstrated. The performance of the fuel was demonstrated. The fast reactor MOX fuel cycle was closed, with the loading into PFR of fuel made from material recycled from fuel already used in PFR. These were all outstanding technological achievements. PFR received a mid-life upgrade and the first steam generators were replaced with ones more suited to a prolonged and reliable service.

Phase 2 of the PFR's life showed that it could achieve the reliability and availability that are needed for a commercial power station. Ultimately, the CFR was not built, and this was because it was not needed. The reason for this does not lie in the mastery of the technology for making and recycling MOX fuels, nor does it lie in the materials issues of safely containing liquid sodium in a steam raising plant. Both of these issues have technical and engineering solutions, but these solutions come at a price. Ultimately, this price will be reflected in the cost of electricity produced.

The real problem for CFR then was, as it is for THORP today, that uranium has turned out to be readily available and cheap

Future Events

The NIG is pleased to announce the next few events which may be of interest to our membership.

Keep an eye out for more details as they are confirmed at:
http://www.iop.org/activity/groups/subject/nig/calendar/index.html

From Magnox to Chernobyl: A report on clearing-up problematic nuclear wastes

On the 28th September 2017 the Nuclear Industry Group will be hosting a presentation by Sean Barlow,a Postgraduate Research Student at the Dept. of Materials Science and Engineering, The University of Sheffield. This presentation will discuss the origins of some of these problematic nuclear wastes and the current plans on remediating them, including disposal in a geological disposal facility (GDF), followed by some of Sean's PhD work on solving these problems. The even will be held at The Centre, Birchwood at 17:30.

Topical Research Meeting on the Physics Driving Innovation Across the Nuclear Industry

The Nuclear Industry Group will be hosting a topical research meeting on the 1st and 2nd of November 2017 at the Victoria and Albert Hotel in Manchester, with a conference dinner to be held at the Museum of Science and Industry. The event will demonstrate the value that Physicists bring to Nuclear Industry, bringing together academia, industry and the supply chain to celebrate recent successes and demonstrate the value of nuclear to UK plc. The event explores how through collaboration, the UK can become a leading, vibrant hub for the nuclear industry.

Women in Nuclear

An event is planned for early 2018 to celebrate the roles of women in physics. The event will provide networking opportunities and career profiles / advice to attendees.

NEA Event

In March 2018 the NIG will be hosting a talk from Jim Gulliford from the NEA, to be held in the Bristol area.

Items for the next newsletter – Submit an Article

We'd like to hear what you're doing, what you think of the Nuclear Industry Group, any ideas you may have for networking opportunities or anything else you think would be of interest to the rest of the Group. We plan to publish the next Newsletter in autumn 2018.

This newsletter is also available on the web and in larger print sizes.

The contents of this newsletter do not necessarily represent the views or policies of the Institute of Physics, except where explicitly stated. In addition the views and opinions stated in this Newsletter do not represent those of the organisations employing the article authors.

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